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6. AUTHOR(S)
Fong, Derek
Monismith, Stephen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Dept of Civil and Env. Eng.
Stanford University
Stanford, Ca. 94305-4020

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
800 N. Quincy St.
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14. ABSTRACT
We characterize the hydrodynamic conditions relevant to a bottom source plume in a nearshore environment. Analyzing a dye concentration data set collected by a state of the art autonomous underwater vehicle and fixed hydrodynamic measurements, we quantify the meandering and lateral dispersion of a plume. We find that both processes are important to ultimate plume fate and transport. The lateral dispersion is governed by a scale-dependent processes that is driven by three-dimensional turbulence in the near field and two-dimensional turbulence in the far field. This project also demonstrates the importance of wave-induced transport in the near shore. We find that it can be significant at times and must be used to supplement measured Eulerian transport in order to accurately model cross-stream plume transport. Finally, we evaluate the accuracy of a bottom-tracked acoustic Doppler current profiler and show that in certain circumstances, there is the potential for a bias error.

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PRINCIPAL INVESTIGATORS: Prof. Stephen Monismith and Dr. Derek Fong

GRANT TITLE: Near-shore hydrodynamic conditions and chemical plume tracking

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OBJECTIVE: Our project goal was to gain an accurate characterization of the hydrodynamic conditions relevant to the dispersal of a bottom source plume in the nearshore environment. Our primary objective was to analyze the extensive hydrodynamic and dye data set collected during the Hydro 4 experiment at Duck, NC in May 2001 to determine the conditions which led to the observed plume advection and dispersal. In particular, with the high resolution data set measured with the REMUS Autonomous Underwater Vehicle (AUV) and fixed hydrodynamic measurements, we hoped to provide a first ever assessment of the role meandering plays in lateral plume dispersion and whether or not the lateral dispersion was a scale-dependent process. Moreover, we sought to determine the importance of wave-induced transport on ultimate fate of the plume.

APPROACH:

In order to assess the lateral dispersion of the dye plume, dye concentration and navigation data collected by the REMUS AUV was processed and used to infer plume concentration profiles from: 1) a fixed downstream distance and 2) at a range of distances downstream from the source. These different transects provided both a picture of the temporal evolution of the cross-stream plume structure and a snapshot of the plume's larger spatial distribution up to one kilometer from the dye source, respectively. In addition, density profiles (calculated and measured by a Conductivity, Temperature, and Depth (CTD) profiler) and velocity fields using an Acoustic Doppler Current Profiler (ADCP) helped characterize the hydrodynamic conditions prevalent over the course of the experiment.

In addition, dye meandering under both wavy and non-wavy conditions were analyzed along with wave amplitude and period information (from a suite of wave gauges) to infer the importance of Stokes drift and wave induced transport.

ACCOMPLISHMENTS: We completed a detailed analysis of the dye plume concentration data set measured during Hydro 4 at Duck, NC to assess the meandering and dispersal of a near-bed coastal plume and the importance of wave-induced

transport of the plume. Our principle results are highlighted below.

Meandering is found to not only advect a plume off of its primary axis, but also to enhance the apparent mean plume dispersion in a fixed reference frame. If one analyzes the plume's lateral dye concentration profile in a moving reference frame following its center off mass, the mean plume is narrower than that measured in the fixed reference frame and better reflects an instantaneous plume profile. We also find that the meandering of the plume can be quantified by a single point measurement of velocity near the plume source. Using data collected by a fixed ADCP, we constructed pathlines and streaklines which compared well with the observed lateral plume variability measured by the AUV at a fixed distance from the source.

Extending the previous work of Stacey, et al. (2000, Continental Shelf Research, vol. 20, 637-663), we analyzed both plume width and peak concentration data as a function of distance from the dye source using a large spatial survey of dye concentrations. This analysis demonstrated that turbulent dispersion is scale-dependent in near coastal flows: the scalar plume grows as a function of how large a spatial extent it occupies. As the plume grows larger, its dispersion increases exponentially. Nevertheless, unlike previous theories which assumed that the scale-dependency exponent $n=4/3$, in our research, we solved for the exponent and found the overall best fit exponent was closer to $n=3/2$. Further analysis using a compound law of $n=4/3$ in the near field and $n=2$ in the far field fit both the concentration and plume data extremely well (correlation coefficients exceeding 0.95). The ramification of this transition from one exponent to another is that in the near field, three-dimensional turbulence governs the diffusive process; in the far field, where the plume grows to scales exceeding the local depth scale, the dispersion is accomplished by two-dimensional turbulence. The consequence is that because of this transition, lateral dispersion increases very rapidly far from near-bed scalar source. The results are presented in detail in an article published in the Journal of Fluid Mechanics (Fong and Stacey, 2003).

The collected dye data was also used to assess the importance of wave-induced scalar transport. We find that under non-wavy conditions where the Stokes drift is small, the simple pathline/streakline model (described above) works well at predicting plume meandering. However, when the waves are more intense, the model does not fair as well: during wavy conditions, the model must be augmented by a Stokes drift velocity (see Monismith and Fong, 2004) in order to accurately match the center of mass dye excursion measured directly by the REMUS AUV. This suggests that any reasonable model of scalar transport in a near coastal

environment needs to carefully consider the effect of wave-induced transport which is not captured by Eulerian transport (velocity) measurements (such as those measured by an ADCP, for example).

Finally, although not one of our primary objectives, we utilized the data collected during several of the previous Hydro experiments to evaluate the effectiveness of using a bottom-tracking ADCP to measure current variability in near coastal flows. We find that there is a significant bias to the reported velocity in the direction of boat/vehicle motion. This finding is important, and ultimately disappointing since it means that one cannot currently utilize existing ADCP technology installed on a REMUS AUV to confidently measure cross-shore currents using typical measurement strategies (i.e., driving the vehicle in cross-shore transects to measure lateral dye profiles). A fixed ADCP is therefore required to accurately infer cross-shore currents and their variability. We published this work recently in the Journal of Atmospheric and Oceanic Technology (Fong and Monismith, 2004).

<u>CONCLUSIONS:</u> The fate of a near-bottom coastal plume is governed by two principle physical processes: advection and dispersion. Advection carries the scalar downstream in the primary flow direction while dispersion dominates both the vertical and lateral dimensions. The lateral dispersion is composed of two different dispersion mechanisms. First, meandering driven by cross-stream current variability can cause an apparent dispersion in the temporal mean unless the plume axis variability is accounted for. Second, the primary and irreversible lateral dispersion is caused by turbulent diffusion. The turbulence is predominantly three-dimensional in the near field and two-dimensional in the far field. Both the two- and three-dimensional turbulence permit the lateral dispersion to be scale-dependent such that the lateral dispersion increases rapidly downstream from the source.

Finally, in a wavy environment, wave-induced transport can be significant and is often comparable or greater than the measured Eulerian transport. For many coastal ocean flow environments, this transport must be accounted for in order to properly model the advection and dispersal of a near-bed coastal plume.

<u>SIGNIFICANCE:</u> Our studies have provided a detailed picture of how horizontal dispersion operates at a coastal site: both via meandering and turbulent diffusion. Our analysis has suggested a framework for coastal dispersion that is consistent with pre-existing turbulence theory and should be applicable at any number of near-coastal sites. This research has also provided a quantitative assessment of the importance of wave-induced scalar transport in near coastal

waters. Finally, we have provided guidance for all users seeking to obtain useful information from bottom-tracked ADCP data.

PATENT INFORMATION: none

AWARDS INFORMATION: none

PUBLICATIONS AND ABSTRACTS:

1. Fong, D.A. and M.T. Stacey, 2003. Horizontal dispersion of a near bed coastal plume, *Journal of Fluid Mechanics*, 489, 239-267.

2. Fong, D.A., and S.G. Monismith, 2004. Evaluation of the accuracy of a ship-mounted, bottom-tracking ADCP in a near-shore coastal flow, *Journal of Atmospheric and Oceanic Technology*, 21(7), 1121-1128.

3. Monismith, S. G., and D. A. Fong, 2004. A note on the potential transport of scalars and organisms by surface waves, *Limnology and Oceanography*. 49, 1214-1217.